WorldWide ElectroActive Polymers

WW-EAP

(Artificial Muscles) Newsletter

December 2001 | WW-EAP Newsletter | Vol. 3, No. 2

http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm

FROM THE EDITOR

Yoseph Bar-Cohen, yosi@jpl.nasa.gov

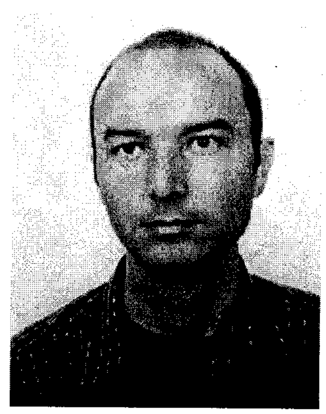
The field of EAP is continuing to grow in the number of investigators and potential users that are considering applications for these materials. The EAP characteristics of inducing large displacements and the functionality that emulates biological muscles are making EAP materials highly attractive. To make these materials actuators-of-choice it is necessary to solidify the technical foundations, namely its infrastructure and identify niche applications where their unique capabilities provide the necessary edge. The availability of collaboration and communication forums and archives including the SPIE and MRS conferences, the WW-EAP webhub, this WW-EAP Newsletter and the recent publication of the SPIE Press book entitled "Electroactive Polymers (EAP) actuators as artificial muscles" are continuing to provide the needed information and cooperation opportunities in support of this broad multidisciplinary field. However, we are continuing to be at a distance from meeting the challenge of an EAP actuated robotic arm that can win a wrestling match against human opponent. While it is a futuristic objective, significant progress has been made in all the elements that are critical to the infrastructure of this field. While researchers and engineers are facing the current challenges to the implementation of EAP it would be productive to consider combinations of EAP and other materials as well as finding applications where properties can be traded similar to the use of a gear in motors where speed is traded for torque.

ABOUT THE EXPERTS

Jiangyu Li

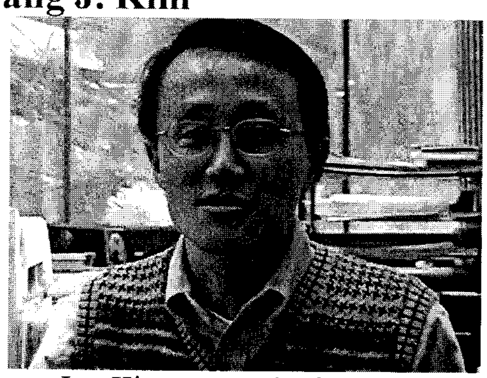
In August, Jiangyu Li joined the Department of Engineering Mechanics, University of Nebraska-Lincoln as an Assistant Professor. He moved from California Institute of Technology where he holds position of Postdoctoral Scholar. At his new affiliation he will investigate structure-property relationship of active materials, including ionic polymer metal composites (IPMC) and ferroelectric polymers. Jiangyu can be reached at jli2@unl.edu or 402-472-1631.

Kenneth Meijer



In September, Kenneth Meijer started a joint faculty position at the Department of Biomedical Technology at the Technical University of Eindhoven, Netherlands www.bmt.tue.nl and the Department of Health Sciences at the University of Maastricht, Netherlands www.fdgw.unimaas.nl. During his post-doctoral research with Dr. Robert Full, at the Department of Integrative Biology at the UC Berkeley http//polypedal.berkeley.edu, he studied how biology can provide inspiration for the development of artificial muscles. He initiated the first direct comparison between biological muscles and several EAP actuators [*SPIE Proceedings 2000 and 2001; Electroactive Polymer (EAP) Actuators as Artificial Muscles, Ed. Y Bar-Cohen, Ch2.2, 2001*]. His studies showed that EAP actuators can operate within the performance space of biological muscles and have the potential to be used as artificial muscles. At his new affiliations his research will be directed at the study of locomotion in able and disabled people. He plans incorporate his work on artificial muscles within this research scope. Specifically, he intends to apply the EAP technology to develop smart rehabilitation devices, like lower limb prosthetics. It is his assertion that EAP actuators are perfectly suited to combine, in a simple and robust design, the actuation and sensing properties that are needed for an efficient prosthetic device that assists locomotion in a natural way. His new e-mail address is: kenneth.meijer@bw.unimaas.nl.

Kwang J. Kim



Kwang J. Kim moved in August from Environmental Robots Inc. (ERI), Albuquerque NM to the University of Nevda-Reno (UNR) where he serves as the Interim Director of Nevada Ventures Nanoscience Program (NVNP) and an Assistant Professor of Mechanical Engineering Department. At UNR, he put together the Active Materials and Processing Laboratory (AMPL). He plans on continuing his research and development at AMPL where he has a fully equipped laboratory for nanomaterials processing/related devices and characterization. His teaching and research interests are broad based, but mainly in Artificial Muscles/Smart Materials, Nanotechnology, and Thermal Sciences/Energy Systems. kwangkim@unr.edu

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GENERAL NEWS

The WW-EAP Webhub is continuing to be updated with information regarding the EAP activity Worldwide. This webhub is hosted at the JPL's NDEAA Technologies Website: http://ndeaa.jpl.nasa.gov

2002 SPIE EAPAD Conference

Since the first SPIE conference on EAP that was held in March 1999, the field of Electroactive Polymers has emerged from its anonymity to the spotlight of the science and engineering community. Indicators of this growth are the number of the number of participants as well as submitted papers to the recent SPIE's EAPAD Conferences including the 2001 and the upcoming 2002. This conference has

grown to four days from two in the first conference. The presentations covered a broad range of topics ranging from analytical modeling to application that constitute the elements of the field infrastructure. The program of the EAPAD 2002 Conference is now available on the internet on
http://spie.org/conferences/programs/02/ss/confs/4695.html

The papers are going to focus on issues that can help transiting EAP to practical use, including improved materials, better understanding of the principles responsible for the electromechanical behavior, analytical modeling, processing and characterization methods and considerations of various applications. To clarify the distinctions between the various EAP materials and operation principles, the Chair divided them into three groups: electronic, ionic, and molecular. The electronic ones are driven by electric forces and involve mostly movement of electrons. The ionic EAPs consist of electrodes and electrolytes and involve mobility/diffusion of cations or anions. The third group is still in infancy and it is involved with a molecular scale EAP. The topics that would be covered include:

- Electroactive polymers (EAP) and non-electro active-polymers (NEAP)
- Models, analysis and simulation of EAP behavior
- Biological muscles as a potential model for EAP actuators
- Methods of testing and characterization of EAP properties and performance
- Support technologies including control, design and fabrication processes
- EAP as artificial muscles and actuators as well as applications of EAP actuators

In 2002, we are going to have another interesting and exciting topic and it is related to biologically inspired robots. This topic is expected to be greatly benefited from the development of EAP actuators in the form of artificial muscles. The speaker will be Prof. Cynthia Breazeal from MIT and the topic of her presentation is "Biologically inspired intelligent robots." This is also the topic of the new book and the editor of this Newsletter and Dr. Breazeal are currently editing. The keynote speaker has been extensively involved with the development of such robots and an example is shown in Figure 1 where the robot Kismet is shown to react to her expressions including smiling.

Another exciting As in the past three conferences we are going have another EAP-in-Action session in which some of the latest practical implementations of EAP will be demonstrated. While some submittals were already made a call will be sent towards the beginning of February to solicit additional presentations. During the EAP-in-Action Session, the attendees are given opportunity to see demonstrations of EAP actuators and devices. This Session is a forum of interaction between the technology developers and potential users as well as a "hands-on" experience with this emerging technology.

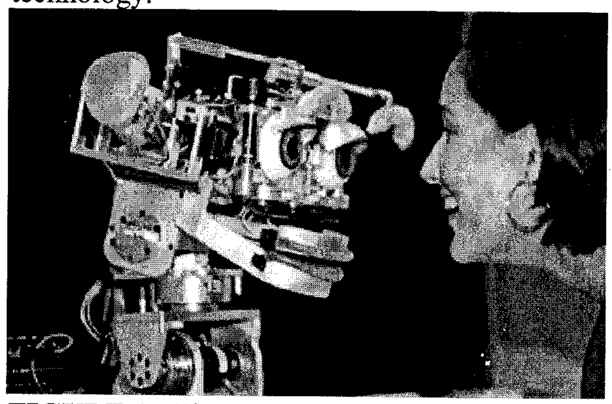


FIGURE 1: The Keynote Speaker, Cynthia Breazeal, MIT, with her Kismet robot responding to her expressions [courtesy of MIT Press Office] http://www.ai.mit.edu/people/cynthia/cynthia.html]

In addition, an Open Panel Discussion Session will also be held to debut the status of the field of EAP, where the conference Chair, Cochair, and the invited speakers will serve as the discussion panelists. Each of the panelists will be given an opportunity to make a short presentation of his/her views and the attendees will be invited to express their thoughts and make comments. This session is intended to stimulate ideas and thought with no attempt to reach a consensus.

2001 MRS Fall Meeting

A Symposium on EAP was included in this year MRS Fall Meeting. This symposium, which is the second for the MRS, was held in Boston from Nov. 26 to 30, 2001. The objective of this symposium was to provide a forum for the EAP researchers to exchange information, stimulate discussions and present the recent advances. The organizers are Siegfried Bauer (Johannes-Kepler Universitaet Linz, Austria), Yoseph Bar-Cohen (JPL), Eiichi Fukada (Koboyasi Institute of Physical Research, Japan), and Qiming M. Zhang (Penn State University). The Invited Speakers are: F. Bauer (ISL, France), R. Fleming (Monash U., Australia), T. Furukawa (SU Tokyo, Japan), H. Kodama (Rion Co., Japan), K. Ikezaki (Keio U., Japan), F. Kremer (U Leipzig, Germany), J. Lekkala (VTT, Finland), M. Marsella (UC Riverside), Geoff Spinks (Australia), Danilo de Rossi (Italy), J. Su (NASA), Y. Tajitsu (Yamagata, Japan), K. E. Wise (USA). A proceedings for this Symposium is expected to be published soon and it would be available from MRS.

EAP ADVANCEMENTS

Leeds University, UK

FORCE AND POSITION CONTROL FOR ARTIFICIAL MUSCLES

R.C.Richardson (email: menrr@leeds.ac.uk), K.Watterson, M.D.Brown, M.C. Levesley, J.A.Hawkes, P.G.Walker.

New actuator technologies are moving closer towards the creation of artificial muscles. For these muscles to behave in synergy with natural human muscle they must be controlled in a similar manner. It has been postulated that the control of human motion is achieved through a force and position control strategy termed *impedance control* [1]. Impedance control does not control either force or position but rather compromises between the two conflicting demands. This relationship between force and position is specified as a mass, spring and damper system.

An impedance controller has been created from a PID position controller and impedance filter feedback loop (Figure 2) [2]. In a position only controller, the control aim is to track a desired position as closely as possible. In this situation the controller still tracks the desired position as closely as possible, however external forces now influence it. The result of the impedance controller applied to a strip of IPMC is shown in figure 3.

The desired position and virtual position are identical for the first 15s as no external force is present. After 15s external forces alter the desired position with the actual position accurately tracking this change.

The external force has modified the IPMC behavior in a predicable manner with the impedance characteristics determining whether the actuator or environment is dominant. It is vital that artificial muscles are controlled by force and position control if they are to successfully interact with their environment.

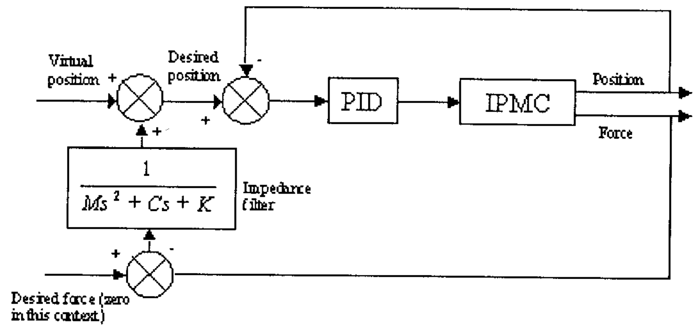
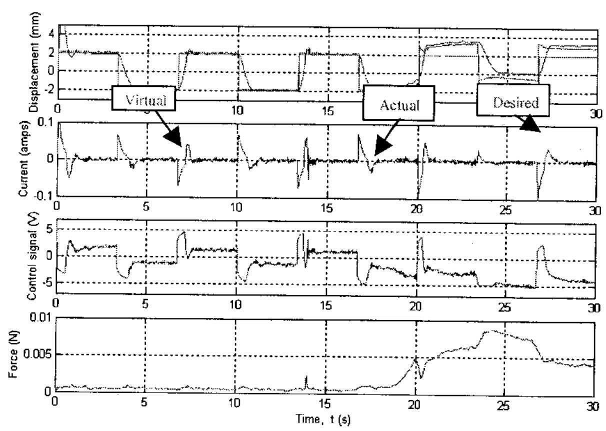


FIGURE 2: Impedance controller block diagram

FIGURE 3: Controller response



Acknowledgements
The authors would like to acknowledge the support of the National Heart Research Fund.

Reference

[1] Hogan N. 'Impedance control: An approach to manipulation part I, II, III'. Journal of dynamic systems, measurements and control. Page(s) 1-24, Vol 107/1, 1985.

[2] Richardson R, Brown MD, Plummer AR. Pneumatic impedance control for physiotherapy. Proceedings of the EUREL int. conf. Robotics. Vol. 2, March 2000.

SKK and UNR cooperation

J. D. Nam, jdnam@skku.ac.kr and
K. J. Kim, kwangkim@unr.edu

A research team from SKK University of Korea and University of Nevada-Reno is developing a number of new electrostrictive polymers based upon novel nano-composite processes. Realizing that a key engineering to the success of modern advanced materials is their tailored material behavior, an effective way to obtain desirable macroscopic properties is related to nano-level materials processing. A new nano-composite, made with intercaliated/ exfoliated organo-modified montmorillonite-"Cloisite", via polyurethane synthesis, is of interest. A successfully synthesized polyurethane nanocomposite shows drastically increased both dielectric constant and ionic conductivity. Such an improvement can be directly translated into a large reduction of operating voltages that is a definite benefit for electrostrictive polymer artificial muscles.

FIGURE 4: A TEM of nanostructured plates – montmorillonite

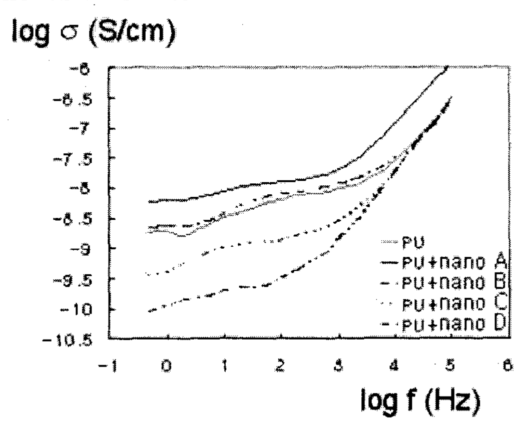


FIGURE 5: Electric conductive vs. frequency

ABB Corporate Research Ltd, Switzerland
Actuation needs for fluid flow guiding vanes

Céline Mahieux[1]
celine.mahieux@alstom.power.com and Christopher Bunce[2] chris.bunce@baesystems.com

Fluid guiding vanes for reversible machinery should enable the switching of the fluid flow from one favored direction to another within a few seconds. The guiding vane application requires large displacements (90° twist minimum) in a few seconds and the use of low voltage. Traditionally, the solution involves a blade with a fixed geometry being able to rotate using a small engine. Smart materials were thought as great candidates to simplify the current set-up and eliminate the need for the engine.

Ionic polymer matrix composites were ordered from Biomimetics Products, Cedar Crest (NM, USA). The material showed a 180° reversible twist under 5 Volts in 2 seconds (See Figure 6). However, the electro-active polymer could not be directly used as a guiding vane for two following reasons: first the lack of stiffness to properly guide the flow and the constant need for current to maintain the bent shape, that would not lead to a cost-viable solution.

FIGURE 6: Biomimetic ionic polymer matrix composite response to 5Volts.

It was then thought to use an unsymmetrical composite laminate exhibiting two tailorable stable positions. The feasibility of this concept was proven using a bi-stable carbon fiber AS4/thermoplastic PEEK composite plate actuated using shape memory alloys (SMA) as shown in Figure 7 (invention disclosure filed). This system enabled the blade twist in less than 2 seconds. However, embedding shape memory alloys in polymers is a difficult task, often limited by a phase transition temperature of the SMA lower than the composite processing

[1] Now Alstom Power Hydro, HGT, Zentralstr., 5242 Birr, Switzerland

[2] Now BAE Systems, Airbus UK, Bristol, BS 99 7AR, United Kingdom

temperature. Furthermore the use of a "glue" to fix the SMA on the blade surface disturbs the surface state of the blade (important for fluid flow) and also leads to very short lifetime characterized by the delamination of the SMA under cyclic loading.

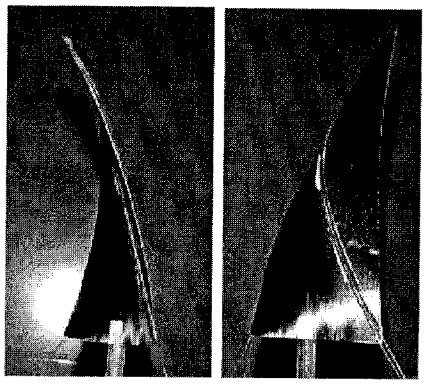


FIGURE 7: Bi-stable composite guiding vane actuated by SMA.

The last step would therefore be to combine the use of electro-active polymers and bi-stable composite blades to achieve a compact, cost-effective guiding vane. The electro-active polymer could be mechanically or chemically bonded to the 2 outer surfaces of the blade and serve as the actuation mechanism. However, two technical shortcomings still hinder the realization of this next step. The force developed by the electroactive polymer was not documented by the supplier and no data could be found in the literature. Performing a very simple experiment involving a common precision scale, enabled the determination of the force developed by the actuated polymer under 5V as a function of the sample length [Reference 1]. The results are shown in Figure 8. The maximum force obtained is rather small (0.06 N) and does not enable the actuation of a 100 x 100 x 1.5 mm AS4/PEEK composite vane.

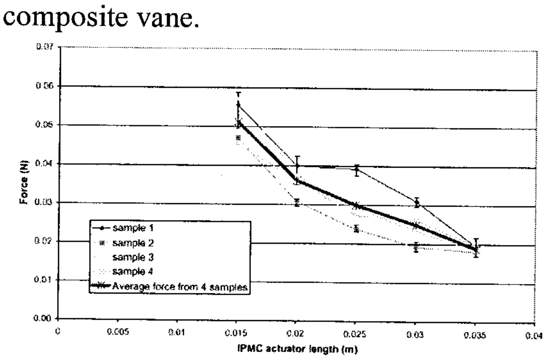


FIGURE 8: Force as a function of the actuation voltage for IPMC.

Materials Research Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan

New Partial Fluoro-Ionomer for Electroactive Polymer Composite - Jen-Luan Chen, Zhi-Hsien Huang, Chih-Yang Yeh, Lon-Cheng Cheng, Tsung-Lung Yang and Wen-Liang Liu

Materials Research Laboratories of Industrial Technology Research Institute in Taiwan has recently found a new type of electroactive polymer composite(EAPC; with Pt electrode) made from polyvinylidene fluoride(PVDF) based partial fluoro-ionomer(PFI) with fluoro- or carbon/hydrogen-polymer matrix.

Film Properties	
Conductivity (S/cm)	10^{-2}~10^{-3}
Tensile strength (Kg/cm^2)	230~310
swelling ratio (%)	10~45
Decompose temp. (°C)	>250

These EAPC/Pt bend in response to low-voltage electric stimuli(<5 Volts), the generated force is about the same scale with the Nafion/Pt, but with 6~9 times bending lifetime. Properties of these EAPC including stiffness, stress, strain, tensile strength and bending curvature can all be tailored easily by simply changing its composition ratio. The fabrication of PFI composite actuators can be simple and low cost.

	MRL Nafion™/Pt	MRL F-Ionomer/Pt
Driving voltage (Volt, 0.5Hz)	< 5	< 5
Displacement (mm)[a]	0 ~ 20	0 ~ 24
Bending life (hr)[b]	1.6	14.5
Bending life (hr)[b-1]	0.13	0.79
Tip force (g)[c]	0.120	0.122
Work density (KJ/m^3)	0.10	0.11

a: specimen size(3mm×30mm×0.2mm) ; at 5V, 0.1 ~ 0.5Hz
b: in 0.1M Na_2SO_4+10mM H_2SO_4 solution; at 5V, 0.5Hz
b-1: in air; at 5V, 0.5Hz
c: specimen size(4mm×35mm×0.2mm) ; at 5V, 0.5Hz

Jet Propulsion Laboratory (JPL)

EAP surface wiper for biofouling and bubbles removal from Electrochemical sensors

Y. Bar-Cohen, yosi@jpl.nasa.gov, X. Bao, JPL

As part of the NRA-00-HEDS-01 a pilot study has been initiated that has a potential for the use of EAP in space application. The study is entitled "Surface Control of Electrochemical Sensors for Water Reclamation." The initial Principal Investigator (PI) has been Michael Hecht and the current PI is Martin Buehler. The goal of this project is to ameliorate problems of biofouling and bubbles that will obscure sensor surfaces in microgravity, using a centimeter-sized wiper made of EAP. An IPMC strip with a miniature brush was made to support the preliminary experiments and the proof of concept. In support of this effort, AIST, Japan, is currently preparing IPMC strips under the lead of Dr. Kinji Asaka. It is hoped that success of this study will be followed by experiments on the Space Shuttle. The breadboard wiper is shown in Figure 9 (h= 7mm and l=5cm) both in steady and activated states. The key concern is the low actuation force that is produced by IPMC and contributions of alternative electroactive materials from the EAP community to this task will be welcomed and properly acknowledged.

V = 0 V

V = -1 V

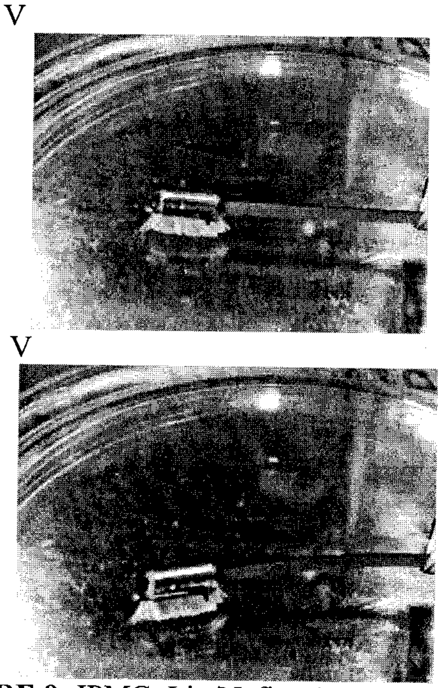


FIGURE 9: IPMC: Li+/Nafion 0.2 mm thick, Voltage: ±1.5V, Tip displacement: ±12 mm

EAP characterization – IPMC time dependent response

Y. Bar-Cohen, yosi@jpl.nasa.gov, X. Bao, JPL

Most past studied of the behavior and characteristics of Ionic Polymer-Metal Composite (IPMC) were focused on the effect of the ions on the material electroactivity [Bar-Cohen, 2001; Nemat-Nasser and Thomas, 2001]. Our recent studies comparing the behavior of Nafion and Flamion based IPMC with revealed that the time response of these materials is significantly different. While the Nafion base EAP reacts quickly in one direction and then relaxes back and even crosses the steady state position, Flamion slowly bends exponentially with time even after several thousands of minutes (Figure 10).

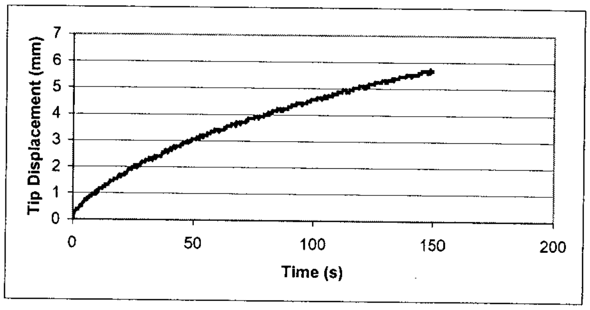


FIGURE 10: Time response of Flamion/Li IPMC

This result that IPMC is highly dependent on the backbone was observed during the ongoing efforts to develop methods for the characterization of EAP materials properties [Stewart and Bar-Cohen, 2001]. An experimental setup was developed for data acquisition from IPMC strips subjected to various signal amplitude and voltage levels as well as tip mass loads. When using a video setup and an image-processing algorithm to track the strip deformation it was determined that a system with 30Hz frame per/sec is too slow to acquire the initial deformation of the Nafion based IPMC. A new system was recently established that allows acquisition at rates of up to 125 frames/sec (Figure 11). The new measurement setup allows the capturing of 2D images of IPMC large deformations (Figure 12). From the real time captured data the strip curvature is extracted as a function of the input voltages, currents and tip force, where the signal shape is controllable.

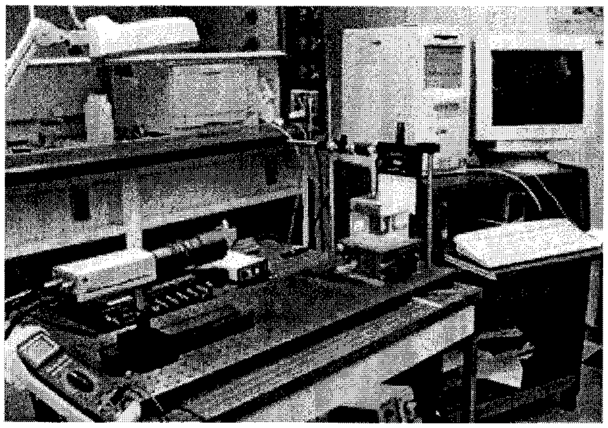


FIGURE 11: Setup for data acquisition of the curvature as a function of various parameters for IPMC.

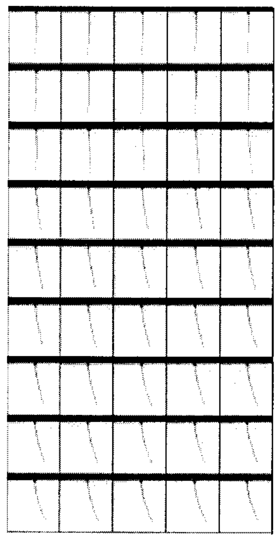


FIGURE 12: Sequence of displacements captured at 125 frames/sec for Nafion/Li IPMC

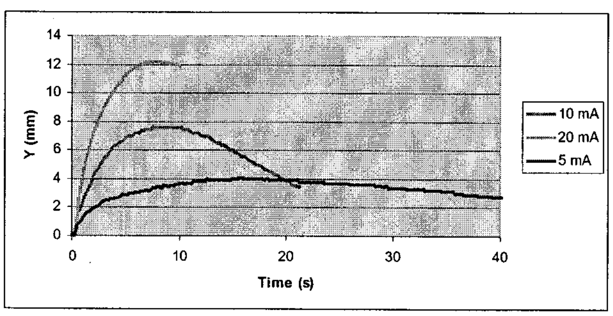


FIGURE 13: Time response of Nafion/Li IPMC

Acknowledgement

This study was conducted under the DARPA's EAPAD contract. The Nafion base IPMC was provided by Prof. M. Shahinpoor from ERI and the Flamion base IPMC was provided by Dr. K. Oguro, AIST.

Reference

Bar-Cohen Y. (Ed.), "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges," SPIE Press, ISBN 0-8194-4054-X, (2001).

Nemat-Nasser S. and C. W. Thomas, "Ionomeric Polymer-Metal Composites," ibid, Topic 3.2, Ch. 6, pp. 139-191.

Sherrit S. and Y. Bar-Cohen, "Methods of Testing and Characterization," ibid, Topic 6, Ch. 15, pp. 405-453.

Space and commercial applications of Cold Hibernated Elastic Memory (CHEM) self-deployable structures - Witold Sokolowski, *Witold.M.Sokolowski@jpl.nasa.gov*

The concept called "cold hibernated elastic memory" (CHEM) utilizes polyurethane-based shape memory polymers (SMP) in open cellular (foam) structures. The CHEM structures are self-deployable and are using the foam's elastic recovery plus their shape memory to erect a structure. In practice, the CHEM foams are compacted to small volume above their softening (glass transition) temperature Tg. They may then be stored below their Tg without constraint. Heating to a temperature above their Tg restores their original shape. The advantage of this exciting new technology is that structures when compressed and stored below Tg, are a small fraction of their original size and are lightweight. The CHEM processing cycle is illustrated in Figure 14 below.
The CHEM foam materials are under development by the Jet Propulsion Laboratory (JPL) and Mitsubishi Heavy Industries (MHI). Currently, the CHEM foam concept is well formulated, with clear space and commercial applications.

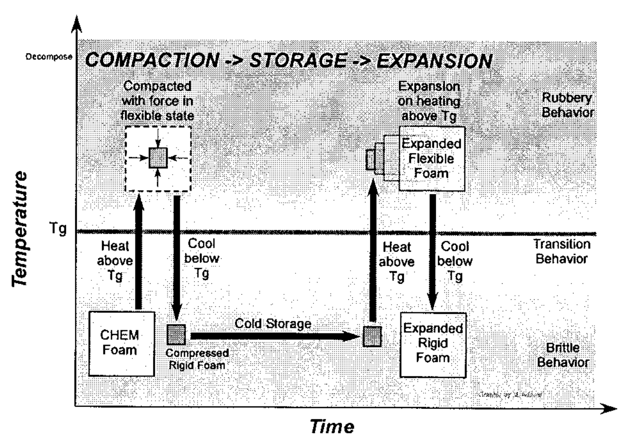


FIGURE 14: CHEM processing cycle

Previous experimental results were very encouraging; the accumulated data indicate that the CHEM foam concept performs robustly in the Earth environment as well as in space. One of examples is the demonstration of CHEM wheels developed for the sub-scale nano-rover. Other potential applications, such as a horn antenna, camera mast, and a sensor delivery system, were studied under various programs at JPL. Besides space structural use, the impact energy absorption applications such as self-deployable soft landing systems and micrometeoroid protection shielding were considered and investigated lately with promising preliminary results.

Although space community is the major beneficiary, a lot of potential commercial applications are foreseen for the "earth environment". The researchers have been already contacted regarding potential CHEM applications in recreation, toy, automotive and biomedical areas.

DESIRED EAP APPLICATIONS

The field of EAP has enormous potential to many areas including almost any aspect of human life. While some ideas may still be science fiction it is important to scope the requirements to the level that current materials can address. The objective of this section is to help accelerate the progress towards practical applications by providing those who are seeking to use such materials a forum to express their need directly to the EAP material developers. Interchange among those who are expressing the need and the material developers is highly welcome and feedback as well as success stories submitted to this Newsletter would be greatly appreciated.

BOOKS & PUBLICATIONS

Biologically Inspired Intelligent Robots

Y. Bar-Cohen and C. Breazeal (Editors)

With today's technology one can quite well graphically mimic the appearance and behavior of creatures (e.g., Shrek and other cartoon movies). It is time to mimic, as close to the real things as possible, to the point that people will say "gosh, this robot looks so real" just like we say about artificial flowers. There is already an extensive heritage of making robots and toys that look and operate similar to human, animals and insects but we have a long way to go. The emergence of artificial muscles is making such possibility a closer engineering reality. The front cover of the book (Figure 15) speaks for itself about the challenges in terms of appearance, operation, facial expression, stability, robustness, etc. The issues that are involved are multidisciplinary including: materials, actuators, sensors, structures, functionality, control, operation, intelligence and autonomy. It might be interesting to deal only with the technical issues but there are also philosophical ones that can be interesting to address. Science fiction provides great inspiration for what can possibly be done with such a capability. After all, the book is about making the electro-mechanical equivalence of cloning.... that can become an issue for public debut.

FIGURE 15: The cover of the upcoming book on biomimetic robots presenting the challenges of making such robots including control, robustness, locomotion, expressivity, etc. (Courtacy of David Hanson, Enterprenuer)

UPCOMING EVENTS

Dec. 13-14, 2001	International Conf. on EAP, organized by AIST, Japan K. Asaka, asaka-kinji@aist.go.jp
March 18-22, 2002	SPIE joint Smart Materials and Structures and NDE, San Diego, CA., Pat Wight patw@spie.org Website: http://spie.org/conferences/calls/02/ss/confs/ss04.html
March 17-21, 2002	Space 2002 and Robotics 2002 Albuquerque, New Mexico. S. Johnson StWJohnson@aol.com
June 10-12, 2002	ACTUATOR 2002, Messe Bremen GMBH, Germany. H. Borgmann, actuator@messe-bremen.de Website: http://www.actuator.de
June 23-28, 2002	14th U.S. National Congress "Soft Actuators and Sensors," Virginia Tech, S. Nemat-Nasser, www.esm.vt.edu/usncam14/
Oct. 31 – Nov. 1 2002	Transducing Materials & Devices, part of Optatech 2002, Photonic Systems Europe, Belgium, SPIE, Y. Bar-Cohen, yosi@jpl.nasa.gov
Dec. 9-11, 2002	Biomimetics and Artificial Muscles, Albuquerque, NM, M. Shahinpoor shah@unm.edu

WorldWide Electroactive Polymers (EAP) Newsletter

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